each member shall observe meteors when possible. (2) That reports are to be sent in at first of each month. These reports consist of the maps and blanks actually used when observing, with additional notes if necessary.

In case an observer may feel unable to undertake the full program of work as outlined, he can still do useful work by counting the number of meteors that fall per hour with careful notes as to the condition of the sky. Anyone who observes between July 20 and August 30 is sure to catch a large number of meteors. The number of meteors seen per hour increases from sunset to dawn, the greatest number generally being seen just before sunrise. The present time of year is a most auspicious one for the beginner in meteor observing. The weather is warm, so that observations can be made in comfort. During the latter half of July and throughout August a meteor may be seen by anyone who has patience enough to watch for 5 to 10 minutes, while two or three or even half a dozen may be seen in this time. The beginner should be cautioned against trying to observe when the sky is not perfectly clear, or when the moon is bright, for then only the very brightest meteors can possibly be seen. Most astronomical work is valuable only when followed up regularly and systematically, but each night's work on meteors is separate and valuable by itself. Each observer will get full credit for all of the work which he sends in to the Leander McCormick Observatory, which by the grant of the National Academy has become the central bureau for meteor observations in America. Here is a splended chance for amateurs to do real astronomical work. [And one may add real meteorological work also.—*Editor*.]

INTERNAL REFLECTION AS A SOURCE OF ERROR IN THE CALLENDAR BOLOMETRIC SUNSHINE RECEIVER.

By ERIC R. MILLER, Local Forecaster.

[Dated: Weather Bureau, Madison, Wis., June 7, 1915.]

The Callendar bolometric sunshine receiver has already been described in the Monthly Weather Review by Kimball,[1] and elsewhere by various investigators. It may be regarded as being, essentially, either a bolometer with both strips exposed, one blackened and the other bright, or a platinum resistance thermometer of the 4-lead compensated type having the thermometer coil blackened and the compensating leads including a bright coil of the same electrical dimensions as the thermometer coil, so that the only difference between the two coils is the blackening. Each coil or strip consists of fine platinum wire of about 12 ohms resistance, wound in two grids in series. The two pairs of grids are arranged checkerboard-wise, as shown in figure 1, upon a mica plate. In receiver No. 9864, the mica plate measures 6.0×6.2 cm, and the grids cover an area about 5.8×5.8 cm. The blackening consists of a coat of shiny enamel painted over and imbedding the "black" grids. The object of the instrument is to continuously register the vertical component of radiation from sun and sky. Hence, the grids are permanently fixed in a horizontal position.

In order to avoid the effects of wind, convection, rain, etc., the grids are sealed into an exhausted, ovoid bulb, part of which forms a hemispherical cover of about 9.1 cm. external diameter. A vertical section of the instrument is shown in figure 2.

It is obvious that reflection, refraction, absorption, and radiation by the glass cover, and by the metal cylinder in which the bulb is mounted, must modify the simple sine law of variation of intensity of the radiation received upon the plate. Of these errors that due to internal reflection alone will be considered here.

It is convenient to consider the bulb enclosing the receiving grids as made up of a hemisperical cover (*a* fig. 2) above the grids, a spherical zone (*b* fig. 2) immediately below the grids, next a conical zone (*c* fig. 2), and finally a spherical segment (*d* fig. 2).

The internal reflection of radiation by the hemispherical cover, *a*, takes the well-known form of the "caustic by reflection."[2] This is an exceedingly important source of error in the Callendar sunshine receiver. The entire beam (*A*, *B*, *C*, fig. 3) projected upon the interior surface of the hemisphere from M to N (fig. 3), less what is transmitted, is concentrated by reflection upon the base of the hemisphere between *A′* and *B′*. The intensity of the reflected light, and the distance that it extends into the

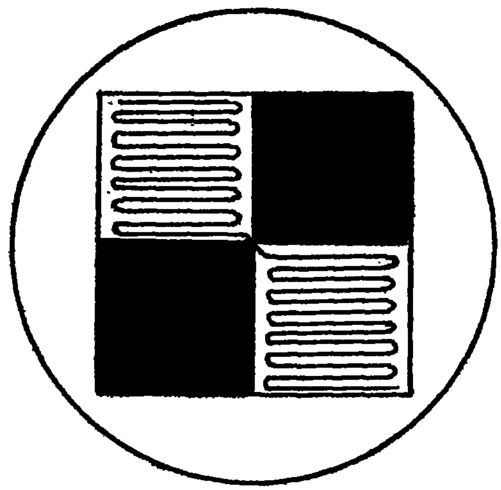

FIG. 1.—Plan of Callendar bolometric sunshine receiver. (Section through the receiving grids.)

hemisphere vary inversely with the elevation of the source of radiation above, or depression below, the plane of the base. According to the geometrical theory of the caustic, for plane waves incident parallel to the base, light reflected in this way extends into the hemisphere a distance equal to half of the radius. Inasmuch as the sides of the grids in the Callendar sunshine receiver extend 0.64 of the radius, and the corners of the grids 0.95 of the radius from the center, it is obvious that the caustic must fall upon the grids. Inspection of the instrument shows this to be the case.

In order to illustrate the changes of form and relative intensity compared with the illumination on a horizontal surface outside the hemisphere, for different elevations of the source above the plane of the base, a series of exposures of photographic plates has been made under a blown glass hemisphere, and are reproduced here in

[1] Kimball, H. H. Total radiation received on a horizontal surface from the sun and sky. Monthly Weather Review, August, 1914, 42: 474-487. (Gives bibliographic references.)

[2] Watson, W. Caustics formed by reflection in "Textbook of Physics," London, 1902 pp. 470-472.
Wood, R. W. Reflection of plane waves from concave spherical mirrors, in "Physical Optics," New York, 1911, pp. 54-63.

figures 5 to 10. The angles of incidence and duration of exposure in making these plates were as follows:

Figure.	Angle of incidence.	Time exposed.
	°	*Seconds.*
5	0	60
6	10	24
7	20	12
8	30	8
9	40	6
10	50	5

The relative areas occupied by the grids of the Callendar sunshine receiver are indicated in outline by black lines on each plate.

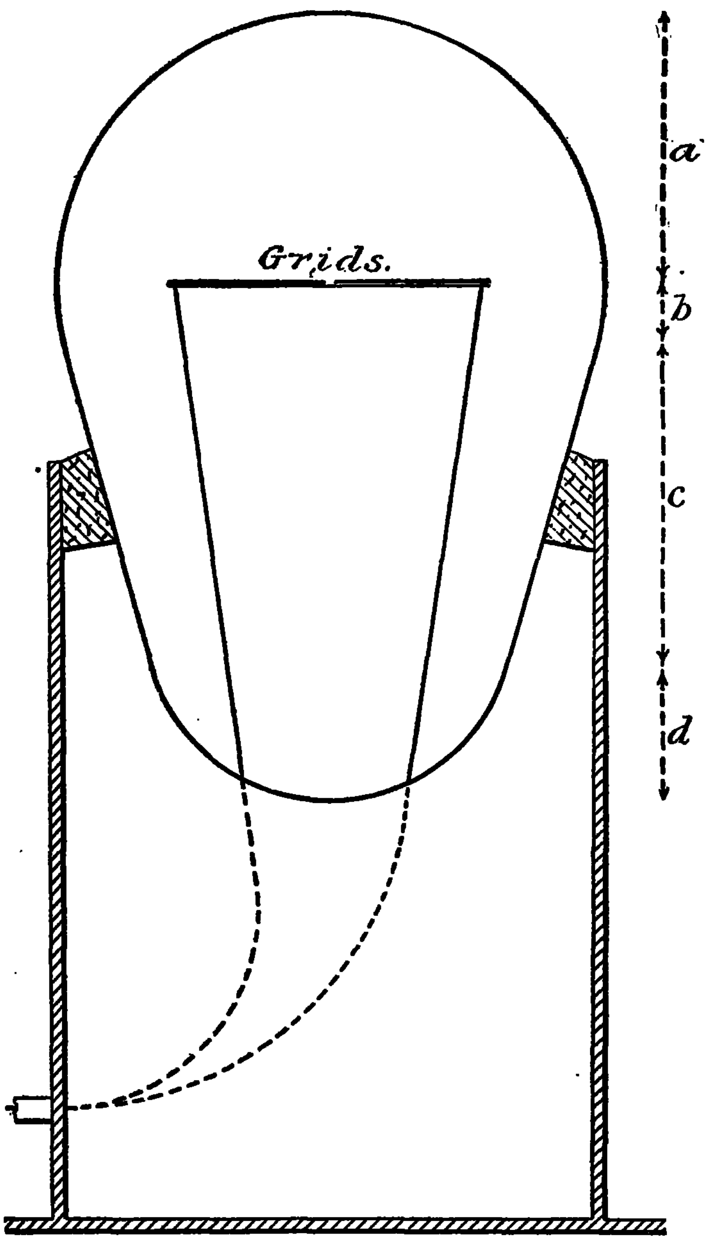

FIG. 2.—Vertical section through the Callendar bolometric sunshine receiver.

The V-shaped illuminated patch, figure 6, in the middle of the grid that the caustic crosses, is the caustic formed by light reflected from the surface of the photographic plate, the path of the ray in this case being as shown in figure 4. Similar caustics may be expected to result from any bright surface near the receiver and slightly below the horizon of the grids, or by reflection from the grids themselves. Reflection from the grids has the peculiarity that radiation projected in this manner falls mainly upon the grid opposite the source, which thus receives radiation reflected from all three of the other grids.

Turning now to internally reflected radiation from below, we have first the spherical zone, about 15° in width, then the conical surface (in Receiver No. 9864, a right

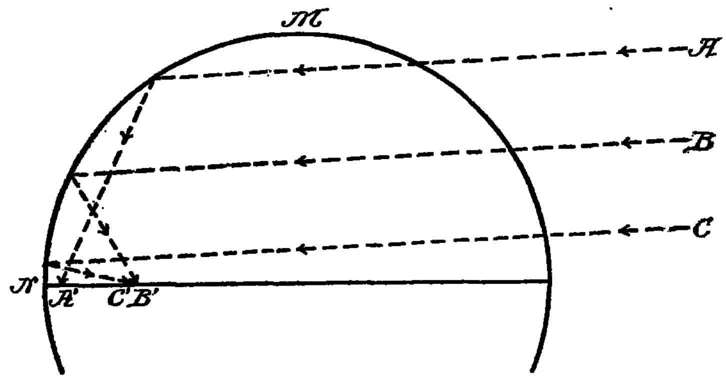

FIG. 3.—Formation of a caustic by the reflection of the beam ABC from the surface MN upon a plate at $A'B'C'$.

circular cone of 15° radius), and finally the spherical segment which is about 3 cm. in radius and about 6 cm. below the grids. The spherical zone forms caustics by reflection on the underside of the grids. These differ in form, but are more concentrated than those formed by the cover. They are of most importance when the source of radiation is low, since the zone is otherwise shaded by the grids. The conical surface is not of much importance since the source must be lower than elevation [solar altitude?] 15° for its reflected light to approach the grids, and then the conical surface is mostly shaded by the walls of the brass cylinder in which the bulb is mounted.

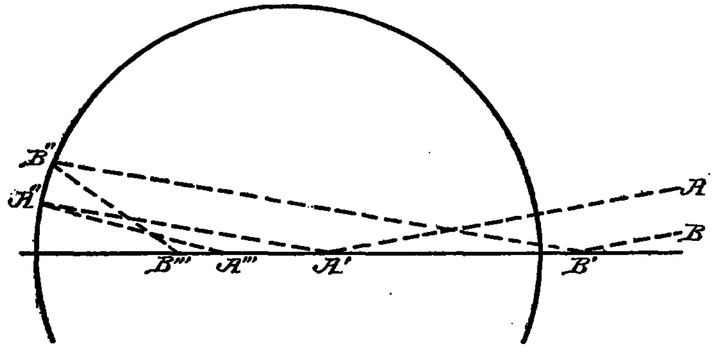

FIG. 4.—Formation of a caustic by internal reflection of light reflected from grids or other surfaces.

The spherical segment at the bottom of the bulb is shaded except for high elevations of the source of radiation, and if it were truly spherical would have no effect in concentrating radiation upon the grids. In all these cases of reflection from below it must be borne in mind that the grids are mounted upon a mica plate whose proper reflection and absorption must greatly diminish the amount of radiation transmitted to the grids.

Inasmuch as the Callendar sunshine receiver depends upon the difference in the temperature of the black and bright grids, it is easy to infer the nature of the error produced by the concentration of radiation upon one of the grids in any of the ways described above. When the excess of radiation falls upon a black grid the difference of temperature between the black grids and the bright grids will be increased and the indicated radiation will also increase. On the other hand, when the additional energy is delivered to the bright grids, both the difference and the indicated energy will be decreased. Since the position of the grids is fixed, while the radiation from the sun is projected successively around the interior of the hemisphere it must be received by a grid of one kind at one time of day and by a grid of another kind at another time of day, with the result that the indicated radiation shown by the recorder is in excess when the caustic falls upon a black grid and is deficient when it falls upon a bright grid. Thus the indicated daily march of radiation will be skewed, or unsymmetrical with reference to noon.

Direct experiments upon the Callendar receiver have been made by turning the receiver so that the reflected radiation is suddenly changed from a grid of one kind to a grid of the other kind. For elevations of the sun up to 20° the results of the experiments are in accordance with the foregoing considerations; but at solar altitude 29° a change in the opposite direction was obtained. The results of four experiments, made on March 23 and April 3, 1915, may be summarized as follows:

Sun's altitude.	Result of reversal (90° rotation).	
°	*Cal. min./cm.²*	*Per cent of total radiation.*
12	0.1	60
14	0.03	9
19	0.02	5
29	−0.06	− 8

In conclusion, it may be remarked that while it may be possible to obtain suitable correcting factors either analytically or empirically, their form would necessarily be so complex as to make their use exceedingly undesirable. The fact that the caustic theoretically does not extend more than a half-radius into the hemisphere, or actually two-thirds if we consider the doubly reflected patch in figure 6, suggests the possibility of redesigning the instrument by changing the shape of the cover and the size of the grids in relation to the cover, to avoid these sources of error.

The photographs illustrating this note were made in the physical laboratory of the University of Wisconsin, and I take pleasure in acknowledging my indebtedness to Prof. B. W. Snow for the use of apparatus, and to Prof. J. R. Roebuck for aid in making the photographs.

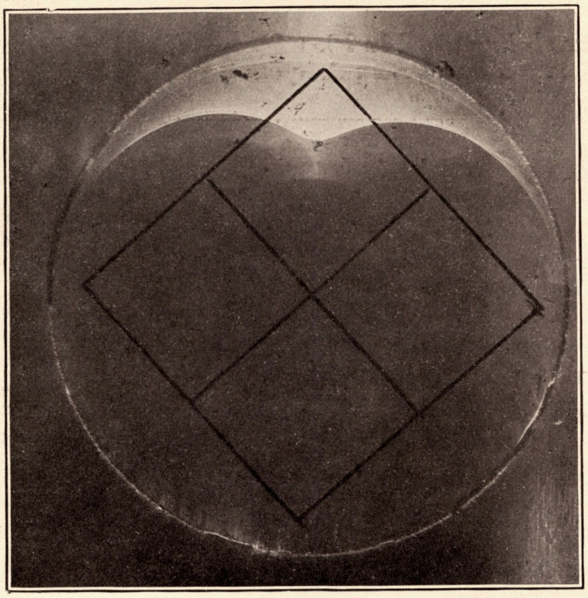

FIG. 5.—Caustic for incidence of 0°.

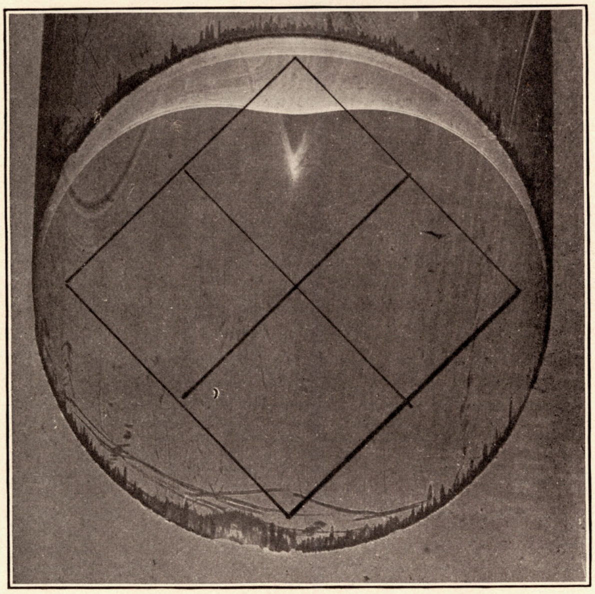

FIG. 6.—Caustic for incidence of 10°.

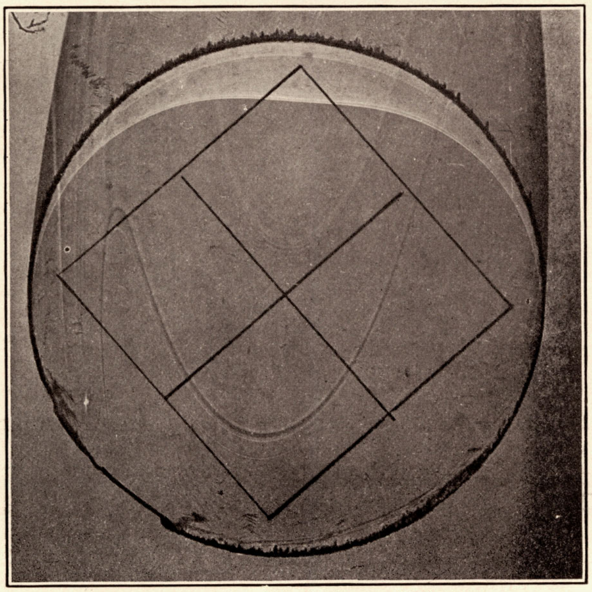

FIG. 7.—Caustic for incidence of 20°.

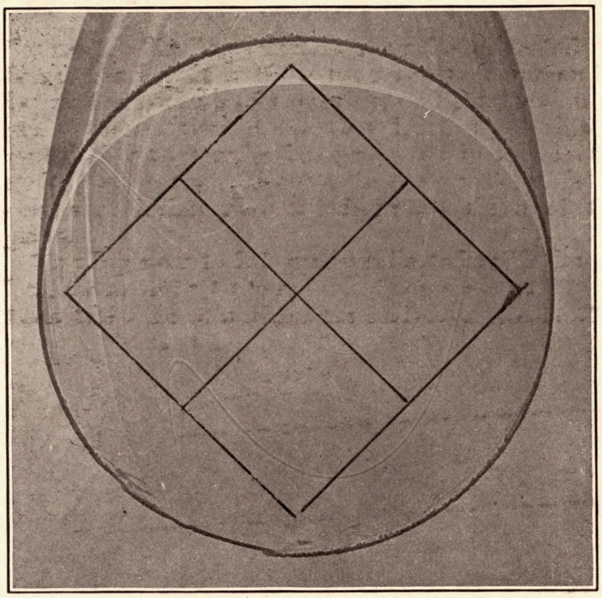

FIG. 8.—Caustic for incidence of 30°.

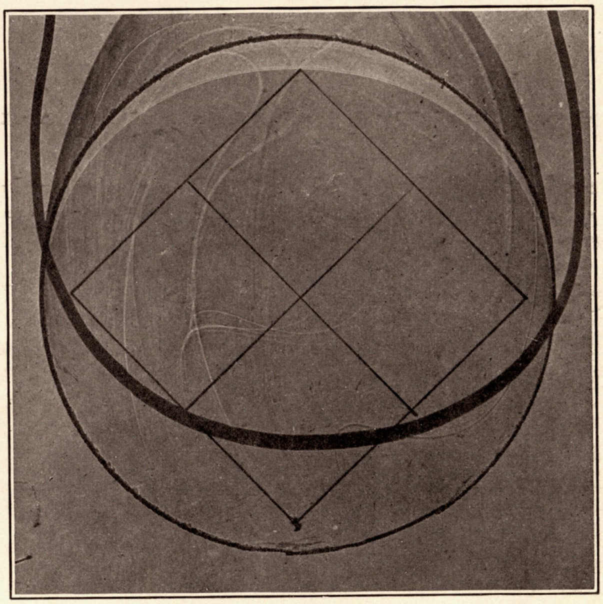

FIG. 9.—Caustic for incidence of 40°.

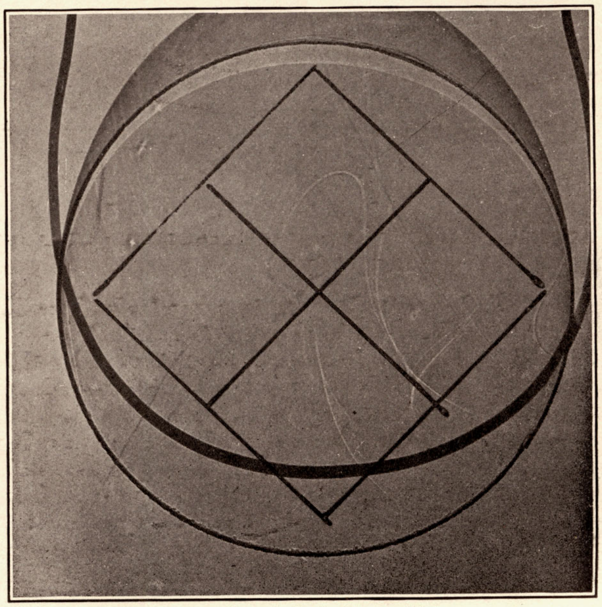

FIG. 10.—Caustic for incidence of 50°.

CAUSTICS OF REFLECTION ON A HORIZONTAL SURFACE WITHIN A GLASS HEMISPHERE.